Predictability and Ensemble-Forecast Skill Enhancement Based on the Probability Density Function Estimation

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LONG-TERM GOAL

My long term goal is to make substantial contributions to enhancement of forecast skills concerning the oceans and atmosphere, by deepening our knowledge for the nature of predictability. I place my emphasis on transition mechanism between dynamical regimes of planetary flows and coherent structures from both Eulerian and Lagrangian points of view.

OBJECTIVES

I wish to develop theoretical frameworks for enhancement of predictability based on dynamical systems theory. To help enhance predictability of sudden and severe events, I wish to investigate transition mechanisms between dynamical regimes. I also wish to throw a bridge between Eulerian and Lagrangian viewpoints and explore impact of severe events on large-scale transport in planetary flows. Knowledge obtained by these predictability studies will lead to a design of comprehensive ensemble-forecast systems and data-adaptive observing systems.

APPROACH

To achieve my goals, I plan to develop new theories and improve already existing methodologies so that they can be combined systematically. I start from assessing and extending individual elements of the theoretical framework, and develop new theories to fill the gaps between them as necessary. My approach involves: identification and detection of the predictability elements, Eulerian and Lagrangian descriptions of the probability density function evolution, treatment of nonlinearity as well as additive and multiplicative stochasity in data assimilation systems. To improve forecast skills for severe and sudden events, I investigate role played by stochastic noises. Severe events can be viewed as rare extreme bursts and therefore may be related to stochastic noises whose probability distribution has heavy tail. I construct a new innovative methodology for data assimilation systems subject to dynamical and observational noises with heavy-tail distributions. To explore impact of transient flow dynamics on large-scale transport, I combine geometrical approach of dynamical systems theory and spatio-temporal data analysis technique.

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14. ABSTRACT
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15. SUBJECT TERMS

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WORK COMPLETED

During October 2000 to September 2001, my focus was on mechanism of transition between dynamical regimes, transport processes associated with low-frequency variability, and development of a new data assimilation methodology.

Mechanisms of the aperiodic, low-frequency dynamical regimes and transition between them have been investigated in the wind-driven mid-latitude ocean circulation. From physical oceanographic point of view, two quantities - transport difference as a measure of geometrical asymmetry and kinetic energy as a measure of global energetics - were used to explain transition mechanism (Chang et. al, 2001). From theoretical and numerical point of view, dynamical systems theories including the pseudo-arc length continuation method were used to study bifurcation sequences (Simonnet et. al, 2001a,b).

To study predictability concerning transition from oscillatory to singular behavior, an idealized, highly-nonlinear dynamical system has been developed (Ide and Sornette 2001, Sornette and Ide 2001). The model is based on interplay between restoring force and hysteria in inertia. An innovative framework to identify precursory indicators of sudden transition has been suggested.

As the first extension of Eulerian transport theory (Ide and Wiggins 2001), preliminary theoretical framework to analyze role in transport played by variability has been developed. The emphasis is on large-scale oceanic and atmospheric flows. The framework combines geometrical approach of dynamical systems and spatio-temporal analysis for coherency in variability.

A new theoretical framework has been suggested, and is being pursued, to incorporate Lagrangian observations directly into data assimilation systems that use Eulerian dynamical models to forecast oceanic or atmospheric flows. This work is being pursued in collaboration with Chris Jones at Brown University under the ONR Predictability DRI program.

Theory of distinguished hyperbolic trajectory has been refined (Ide et al. 2001).

RESULTS

Two types of mechanism play a role in transition to aperiodic behavior in wind-driven ocean circulations: 1) lose of stability in one of the two limit cycles; 2) growth of the other limit cycle to form a homoclinic connection by reaching the unstable steady state. Spontaneous transitions between dynamical regimes with interannual and interdecadal variability involve global bifurcation associated with homoclinic and heteroclinic connections (Figure 1).

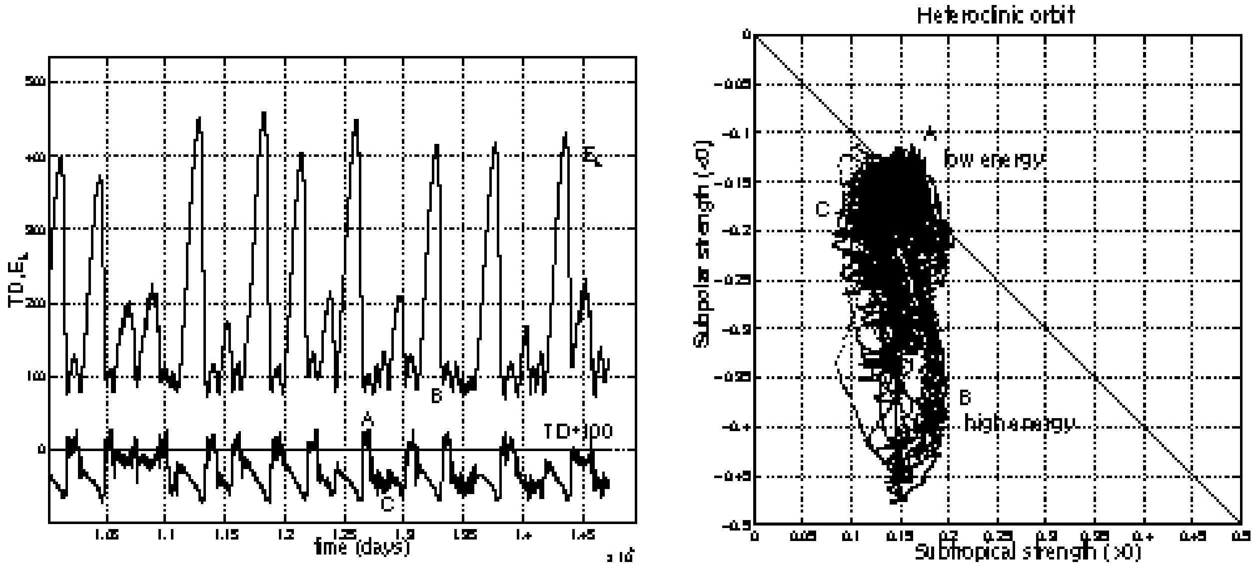

Figure 1. Intrinsic transition between dynamical regimes
[left: time series of kinetic energy (KE) and transport difference (TD);
right: heteroclinic connection for regime transition that occurs on the diagonal line]

Nonlinear interplay between restoring force and hysteria can create a singularity in finite time decorated by accelerating oscillations. The power law singularity results from highly nonlinear growth rate. Based on dynamical systems approach, transition point from oscillatory to singular behaviors can be identified. Theoretical prediction of the exponents concerning the physical quantities of the transition is verified by numerical simulations (Figure 2).

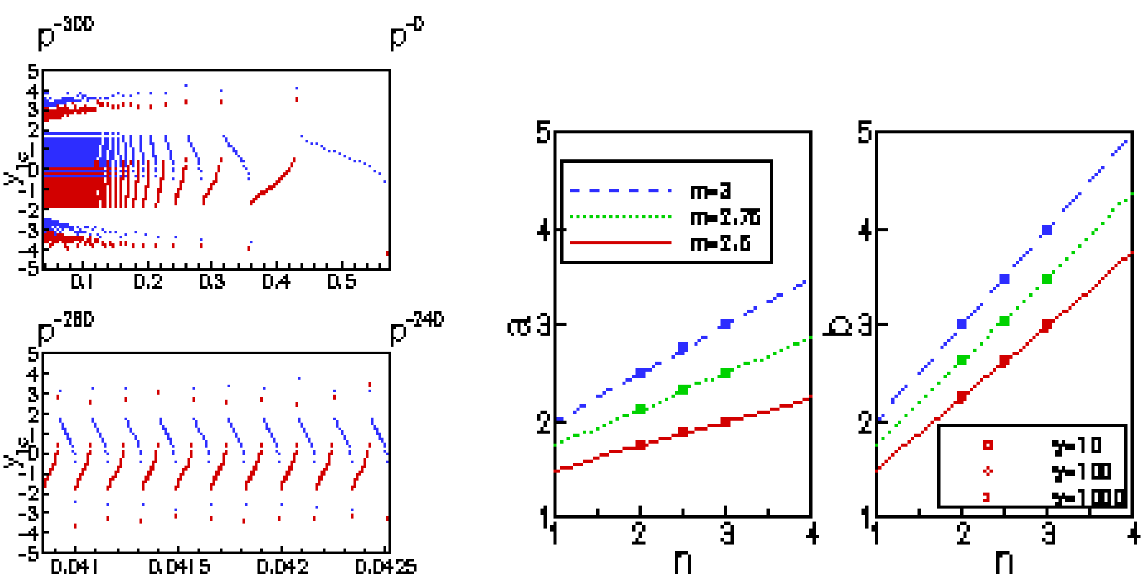

Figure 2. Transition dynamics from oscillatory to singular behavior
[left: fractal properties over 300 oscillations prior to transition at $_{0}$ and magnification over 260th to 241st oscillation; right: theoretical prediction of the exponents (lines) and verification by numerical simulation (symbols) for the transitory dynamics]

Two key elements of transport processes are identified for large-scale planetary flows. First is spatially nonlinear interaction between the (steady) reference and (unsteady) anomaly fields. Second is linear regression between spatial and temporal components of instantaneous flux. Transport associated with variability can be explained in terms of physical processes in the flow dynamics. Impact of specific events in flow dynamics can be predicted.

IMPACT/APPLICATION

Estimating properties concerning transitory dynamics from oscillatory to singular regimes can help enhance predictability of such systems that have log-periodic critical oscillations. The new framework developed in this work can be generalized for application of many physical systems (Sornette 1998, and references therein).

Extending Eulerian transport theory (Ide and Wiggins 2001) offers a variety of new directions for large-scale planetary flows, including analysis of transport processes and mechanism, impact of specific events in the flow dynamics, as well as role played by variability.

The new data assimilation methodology currently being developed in this work can fill the gap between data assimilation and dynamical systems approach to Lagrangian transport theory, which has been one of the focuses in the ONR predictability DRI program.

TRANSITIONS

The new framework for identification of the system with transitory dynamics from oscillatory to singular behavior is being implemented to study log-periodic oscillation associated with stock market crashes.

RELATED PROJECTS

1– NASA data assimilation on data assimilation in ocean-atmosphere coupled system, in collaboration with Michael Ghil (UCLA).

2– Caltech President funds on a new geometrical approach to Eulerian transport, as an application to the ocean circulation in collaboration with James C. McWilliams (UCLA) and Yi Chao (JPL).

SUMMARY

During October 2000 to September 2001, my main contributions to the scientific base were development of new theoretical frameworks in the following fields: transitory dynamics for the systems with log-periodic criticality; identification of physical processes in transport to enhance predictability; sequential data assimilation to incorporate Lagrangian observation. In the next two years, I plan to continue my efforts with emphasis on data-assimilation system design by exploring effect of non-Gaussian stochasity (Sornette and Ide 2001) and developing optimal observing systems using Lagrangian observations. I also plan to extend transport theory into new directions. My institute at UCLA hosts experts in geophysical sciences who work rather independently of each other. Because of this ONR support, Didier Sornette and I have started a collaboration to bring his expertise in earth

sciences and mine in dynamical systems and fluid dynamics. This collaboration could have not been realized without the support from this ONR program.

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